

# HEAVY BARYONS - DIFFERENT FACETS OF EXPERIMENTAL RESULTS

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## 1 Introduction

In this article we will discuss the various facets of heavy baryons considering the life cycle of such objects. Although the physics involved is very different (it spans from perturbative and non-perturbative QCD describing heavy baryon production (birth) over quark-models and Heavy Quark Effective Theory (HQET) modeling the spectroscopy (life) to Heavy Quark Expansion used to describe their lifetimes and decay asymmetries (death). At the end we will give an outlook into the future, describing further studies worth being performed on this specimen.

The field of light baryons, made up of u and d-quarks has been subject of studies for many decades and has led us to a first understanding of baryon structure and the underlying forces. One might thus ask the question why the study of heavy baryons<sup>a</sup> is still of any interest, in particular as this specimen is difficult to come by, the study of their properties is thus an experimental challenge. The common answer of the theorists is clear: the heavy quark constitutes a static colour source which reduces the 3-body problem to an effective 2-body one. Static colour sources can be dealt with 'easily' and their transitions into other (almost) static colour sources can be described theoretically much easier than in the relativistic case.

The study of such objects also allows to probe existing models in a different mass regime. In addition, the quasi decoupling of the heavy quark from the light quarks (in the spin degrees of freedom) leads to a new arrangement of relevant quantum numbers and a reordering of states concerning their mass splitting. This has practical consequences as heavy baryons with large excitation energy turn out to have rather narrow decay width and are 'easy' to observe as compared to their light colleagues.

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<sup>a</sup>Although heavy baryons usually are referred to as being made from at least a c- or b-quark, we will also include some strange baryons in this paper, as no other talk on this conference dealt with them.

One might still ask the question: 'who cares?'. Lets briefly give some arguments why the study of the different aspects of life is still interesting and gives heavy baryons a particular place in hadron physics.

- Production - distinguishes *hard* and *soft* processes (*QCD* and *fragmentation*)
- Mass splitting - tests mass dependence of the effective interaction  
- separates degrees of freedom (*light* versus *heavy*).
- Decays - separates quark-*decay* and quark-*correlations* in hadrons

## 2 Birth - Heavy Quark Production

The production of heavy baryons is usually treated as a two-step process, the production of a heavy quark pair and its subsequent hadronization. While the heavy quark production is a process which can be described in perturbative field theories (QCD for hadro-production and QED or SU(2)xU(1) for electro-weak production) the fragmentation into hadrons is subject to models. The heavy quarks must find suitable partners (typically light quarks) to form observable hadrons which requires their existence in the small part of phase space allowing a fusion of all future constituents. These other quarks can either be created in the fragmentation process (the successive breakings of the colour flux tube stretched between the heavy quark pair) or could be picked from a premordially existing system (the remnants of the hadrons participating in the initial interaction). While the first process has been studied to great detail in  $e^+e^-$  collisions and is now modeled with good precision based on Monte-Carlo techniques, the latter process is still not understood.

### 2.1 Total cross sections in hadro production

We shall thus start with an overview on hadro-production of heavy baryons. Fig.1 shows the cross section of heavy quark pair production as a function of the effective beam energy in fixed target experiments with incoming baryons. The figure depicts two features.

- The curves denote the result of QCD-calculations<sup>1</sup>. In these calculations factorization is assumed to separate *soft* and *hard* processes calculated to second order. The different curves denote the results under variation of different parameters, the quark mass and the factorization scale. While the effective quark mass is a principle unknown the strong dependence on

the factorization scale denotes the effective problems of the calculations. In general the cross section is expected to rise with beam energy.

- The large spread in experimental results over a wide range of energies shows the conceptual problem of extracting the total charm cross section from data. Experiments usually detect a limited number of different charmed hadrons (baryons and mesons) in only part of the phase space. Thus, extrapolation to the rest of the phase space and to unobserved species has to be done. Since  $q\bar{q}$ -correlations (and the respective hadron-correlations which are governed by leading particle effects) are not known, charm counting leads to systematic uncertainties.

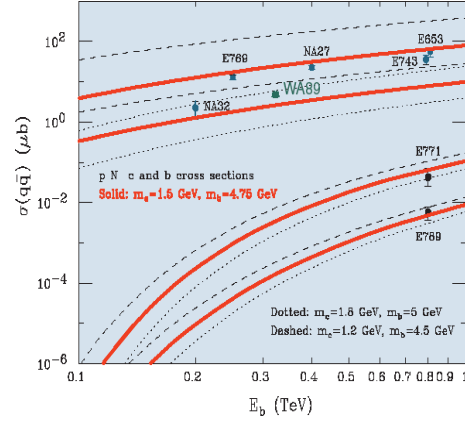


Figure 1. Hadroproduction cross sections for heavy flavours. The pair of lines denote different results depending on the quark masses and factorisation scales.

## 2.2 Heavy quark hadronization in hadro-production

Fig.2 shows the resultant signals observed in charm production by high energy  $\Sigma^-$ -hyperons of 330 GeV/c in the WA89 experiment at CERN <sup>2</sup>. The hyperon carries strangeness and baryon-number and both can be found in the kinematical projectile region ( $x_F \geq 0.3$ ), where the experiment has large acceptance. We see a dominant asymmetry in the baryon over anti-baryon production ( $\Lambda_c$  over  $\bar{\Lambda}_c$ ) and an efficient association of the  $\bar{c}$ -quark with a strange quark in the meson sector. The typical preference of hadronization into mesons is not observed and the asymmetries in the meson sector indicate an 'eating up' of the  $c(\bar{c})$ -quarks by the quark remnants of the projectile.

This feature is also confirmed by first data from the hyperon beam experiment E781 at FNAL using a 600 GeV/c beam <sup>3</sup>. Enough statistics could be accumulated to determine with good accuracy the  $x_F$ -dependence of  $\Lambda_c$  production for different projectiles. Fig.3 shows observed signals (preliminary

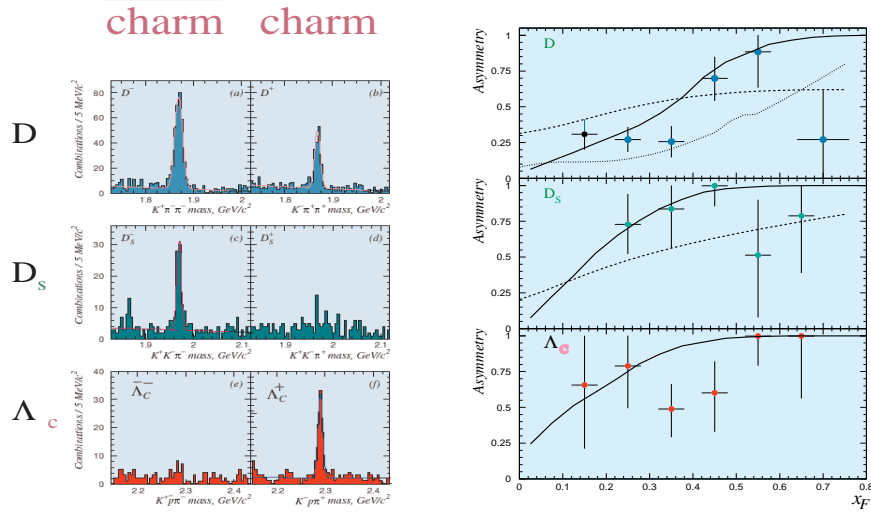


Figure 2. Charm production asymmetries observed in a 330 GeV/c hyperon beam at CERN. Left and right histograms show the invariant mass distributions of final states for  $D^-$ ,  $D_s^-$ -mesons,  $\Lambda_c^-$ -baryon and their anti-particles, respectively

data) for  $\Lambda_c$  and  $D$ -mesons (and their anti-particles) for  $p$ ,  $\pi$  and  $\Sigma^-$  beams. Again, large baryon asymmetries are observed for baryon beams (much less for  $\pi$ -beam), much smaller and reversed asymmetries for  $D$ -mesons.

### 2.3 Photo-production of heavy baryons

While charm production constitutes only about 1/1000 of the total cross section in hadron beams this ratio is much more favorable for photon beams (1/100). This property is the basis of the very large data sample on charmed hadrons obtained by the latest photo production experiment at FNAL, E831. A total sample of about 10k  $\Lambda_c$  in the final state  $p\bar{k}\pi$  may be expected from this experiment<sup>4</sup> with an excellent signal/background ratio of almost 10. Combining  $\Lambda_c$ , selected with less stringent criteria, with slow pions in the same event shows signals for the well known  $\Sigma_c$  in all three charged states as well as the excited  $\Lambda_c^*$ , when combined with two pions, using only about 10% of their data. Although baryon production constitutes only about 1/10 of charmed hadrons in photon induced reactions (in the forward hemisphere) these data

will constitute the largest data set in this field for the near future.

In  $e^+e^-$ -colliders heavy quarks are produced via the coupling of the photon to the charge of the quark, resulting in very large partial cross sections ( $\sigma_{c\bar{c}}/\sigma_{tot} \approx 0.3$  and  $\sigma_{b\bar{b}}/\sigma_{tot} \approx 0.1$  at  $\sqrt{s}=10.4$  GeV). CLEOII, running at the CESR storage ring at Cornell cannot produce beauty baryons owing to the low energy. Charmed baryons are either produced by fragmentation of the c-quarks produced (leading to a hard momentum distribution) or by decays of beauty mesons (resulting in a soft momentum distribution). The latter sample does not play a role in most of their analysis owing to the condition that the baryon should carry at least 50% of the beam momentum which is applied to clean the data samples.

At very high energies  $\sqrt{s}$  of about 90 GeV (at LEP), heavy quark production is governed by the electro-weak coupling to the quarks ( $\sigma_{c\bar{c}}/\sigma_{tot} \approx 0.13$  and  $\sigma_{b\bar{b}}/\sigma_{tot} \approx 0.16$ ). Again, baryons constitute about 10% of the resulting heavy hadrons<sup>5</sup>.

### 3 Life of heavy baryons - Spectroscopy

The mass of a heavy baryon can be viewed as a sum of quark rest masses and interaction energy. In a constituent quark model<sup>6</sup> depicted in fig.4 these terms are:

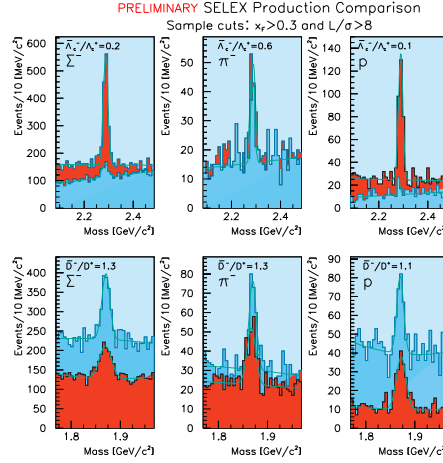


Figure 3. Charm production asymmetries observed in a 600 GeV/c negative beam at FNAL. The pictures show the invariant mass plots for leading and non-leading charmed hadrons for different projectiles. Data are preliminary.

- effective masses of constituent quarks
- kinetic energy
- two-body interaction:
  - potential energy (confinement)
  - spin-spin interaction ( $\mu_q \sim 1/m_q$ )
    - $\Delta m(\Lambda - \Sigma)$  increases with  $m_Q$
    - $\Delta m(\Sigma^* - \Sigma)$  decreases with  $m_Q$
  - spin-orbit interaction (tensor force)

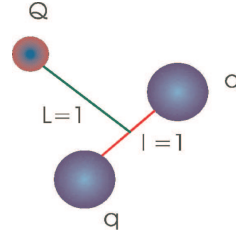


Figure 4. Separation of quark degrees of freedom in a heavy baryon.

As mentioned in the introduction the distinct heavy mass of one constituent inside a baryon leads to a separation of *heavy/light* degrees of freedom. This may become clear in the following example:

Consider the case for unit orbital momentum. We can have  $l=1$  of the light quark pair.  $J^P$  of the light quark pair results from a coupling of its total spin  $S$  with  $l=1$  ( $0^+, 1^+ \otimes 1^-$ ). To this, the heavy quark ( $J^P=1/2^+$ ) couples (although weakly due to  $H_{int} \sim 1/m_Q$  leading to almost degenerate doublets) resulting in 7 different states, for  $\Lambda$  and  $\Sigma$ , respectively. The resulting states will separate in energy from the case of  $L=1$ , orbital momentum between the light quark pair and the heavy quark (for  $\Lambda$   $L=1$  states have lower energy than  $l=1$  states since the attractive spin-spin force in the light diquark requires large wave function overlap, thus  $l=0$ ). Since the configurations become distinctly different (since  $l$  and  $L$  become different quantum numbers) the decay path of  $l=1$  states is altered, thus altering also their decay widths (see section 3.2).

### 3.1 Measurement of the mean square charge radius of the $\Sigma^-$

Before we probe baryon structure using spectroscopic data, we shall first consider the classical approach of electron scattering applied to simple strange baryons. This year has seen the first determination of the mean square charge radius of the  $\Sigma^-$ -baryon, using electron scattering in inverse kinematics. The technique of scattering beams of unstable particles from electrons off a target nucleon had already been employed for the  $\pi$  and kaon. In the two hyperon beam experiments at CERN and FNAL heavy targets have been used for the first time. The technique was developed by WA89. Events were identified and analyzed using a kinematic fit to all observables (momentum measurement of incoming and outgoing hyperon, determination of electron emission angle and its momentum).

The  $Q^2$  dependence of the scattering cross section in this first measurement is depicted in fig.5. The resulting fit to the slope of the form factor at  $Q^2=0$  gives  $\langle r^2 \rangle_\Sigma = 0.91 \pm 0.32 \pm 0.4 \text{ fm}^3$  with the first error reflecting the statistical uncertainty and the second one the systematic one<sup>7</sup>. E781 has obtained larger samples and owing to their larger beam momentum also obtained a larger accessible  $Q^2$ -range. Their preliminary result is  $\langle r^2 \rangle_\Sigma = 0.60 \pm 0.08(\text{stat.}) \pm 0.08(\text{syst.}) \text{ fm}^3$  (see also contribution of I.Eschrich to this conference<sup>8</sup>).

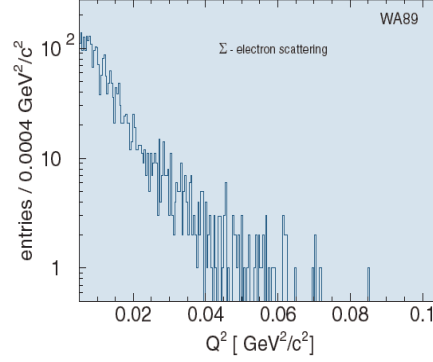


Figure 5. First measurement on the differential distribution for  $\Sigma^-$ - $e^-$ -scattering in a hyperon beam at CERN.

### 3.2 Spectroscopy of strange and charmed baryons

Before moving to heavy baryons, we shall mention new results on the field of strange baryons.

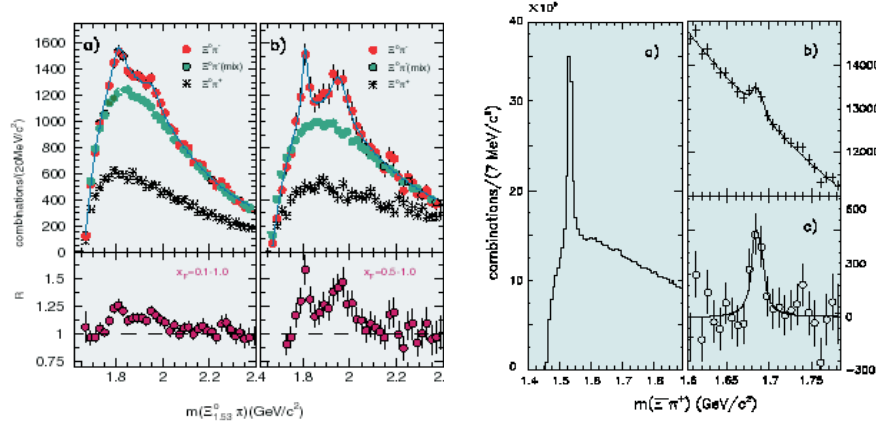


Figure 6. Largest data sample on  $\Xi^*$  resonances observed in the CERN hyperon beam experiment. Left:  $\Xi^*\pi$  invariant mass distributions showing the  $\Xi(1820)$ ,  $\Xi(1955)$ . Right:  $\Xi\pi$  invariant mass distributions exhibiting a signal for the  $\Xi^*(1530)$  and  $\Xi^*(1690)$

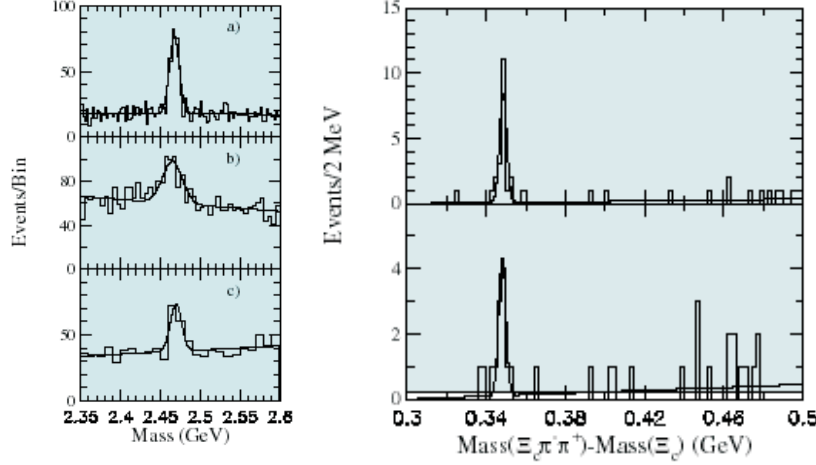


Figure 7. Left histograms: Sum of all  $\Xi_c$ -daughter baryons in various decay channels. Right histograms: invariant mass difference of  $\Xi_c\pi\pi$  and  $\Xi_c$ , latter one for positive and neutral charge states (upper and lower, respectively). Not shown are the mass distributions for the intermediate  $\Xi_c\pi$ -states, showing a dominant signal at the  $\Xi_c^*$ -mass.

The most recent results on spectroscopy (and the only one shown at this conference) concern the largest data sample on  $\Xi^*$ -resonances observed (see fig.6), namely the  $\Xi(1690)$ ,  $\Xi(1820)$ ,  $\Xi(1955)$  decaying into  $\Xi\pi$  and  $\Xi^*(1530)\pi$ , respectively<sup>9</sup>. For the  $\Xi(1690)$  it's the firm confirmation of its existence, for the other two the first observation of this decay channel. The latter ones are produced predominantly in forward direction ( $x_F \geq 0.5$ ) indicating a diffractive production process.

Newly observed states in the sector of charmed strange baryons come from CLEO<sup>10</sup>. They have identified for the first time an orbitally excited  $\Xi_c^*(3/2^-)$ , decaying into  $\Xi_c^*(3/2^+)+\pi$  (see fig.7). Although showing an excitation energy of about 350 MeV the state is still narrow. The explanation for its width together with the spin-parity assignment is shown in fig.8. Here we have separated two classes of states, those with  $l=0$  and  $l=1$ , the angular momentum of the light quark pair. Spin parity of the light quark pair is indicated on the figure together with the spin-parity of the total baryonic system. We assume that the spin of the heavy quark does not participate in the interaction (full separation of *light* and *heavy* system). Considering the light systems, the  $3/2^-$  state can go via S-wave to the  $3/2^+$  state and via D-wave to the symmetric  $1/2^+$  states.



Similarly, the  $1/2^-$  state can go via D-wave to the  $3/2^+$  and via S-wave to the symmetric  $1/2^+$  state. In both cases the decay to the anti-symmetric ground state could be forbidden by parity conservation in the light diquark. Thus, the  $3/2^-$  state is expected to be narrow and decay predominantly to the  $3/2^+$ -state, as observed. The  $1/2^-$ -state will preferably decay into the symmetric ground state difficult to observe. These arguments follow the line already employed for the  $\Lambda_c$ -system.



Figure 8. Decay scheme for  $\Xi_c$ -resonances in HQET assuming decoupling of light and heavy quarks

Fig.9 shows the excitation spectrum for the strange and heavy baryons. The zero-point of the energy scale is matched to the lowest lying baryon-states of the flavor family. As is expected from quark models the spin symmetry of a light quark pair governing the HF-interaction leads to an increased  $\Lambda$  and  $\Sigma$  splitting states with increasing *heavy* quark mass ( $\Lambda - \Sigma$  vs.  $\Lambda_c - \Sigma_c$ , which is compensated if the mass of the *light* quark system is increased ( $\Lambda_c - \Sigma_c$  vs.  $\Xi_c - \Xi'_c$ ). The  $1/2^+-3/2^+$  splitting decreases with the mass of the *heavy* quark but increases with the mass of the *light* system ( $\Sigma$  vs  $\Xi$ ,  $\Sigma_c$  vs  $\Xi_c$ ). The excitation energy of the  $3/2^-$  states slightly increases with the mass of the *light*-system ( $\Lambda_c$  vs  $\Xi_c$ ). As the light and strange quark pairs change role for the  $\Sigma$  and  $\Xi$  (and thus the definition of  $l$  and  $L$ ) the situation is different in the strange sector.

Unfortunately, no published data yet exist for the b-baryon sector.

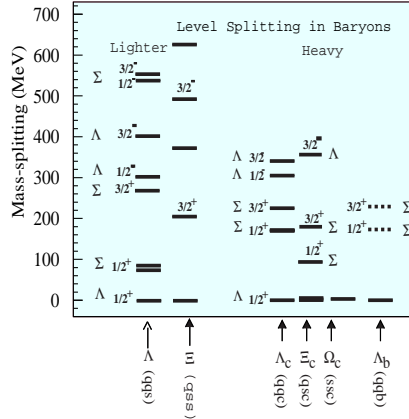


Figure 9. Summary of heavy baryon spectroscopy as of today. Denote the zero-suppression of the mass scale for different flavor compositions (s,c,b-quarks)

Previously reported results on the  $\Sigma_b$  and  $\Sigma_b^*$  showed anomalously high spin splitting which were not confirmed. However, the mass of the  $\Lambda_b$  has now been measured by CDF<sup>11</sup> in the decay channel  $\Lambda_b \rightarrow J/\Psi \Lambda$  to  $5624 \pm 9$  MeV/c<sup>2</sup>.

#### 4 Death of heavy baryons - Decay Properties

The interest in studying decays of heavy baryons is again related to the static colour source and the large mass of the decaying quark. The large phase space available in the quark decay ( $Q\text{-value} \gg m_\pi$ ) results in little influence of particular selection rules like isospin in the strange baryon sector. In addition, the decay of the baryon may be considered as a two-step process: decay of the heavy quark (at first order independent of its surrounding) and subsequent fragmentation of the resulting system. However, this simple picture has proven wrong as is reflected in the large variation of baryon lifetimes even for b-baryons. This has its origin in the large effects of quark correlations which in turn depend on the wave function overlap at the origin. While the free quark decay rate is governed by phase space ( $\sim m_Q^5$ ) and quark mixing ( $\sim V_{cs}$ ,  $V_{cd}$  and  $V_{bc}$ ) the influence of the other quarks decreases with the decreasing localization overlap of heavy and light quarks ( $\Delta r \sim 1/m_Q^2$ ). The result is a modification of branching fractions and decay asymmetries.

##### 4.1 Lifetimes of heavy baryons

Fig.10 depicts two possible processes (out of four) governing the heavy baryon decay, namely the 'free quark decay' (or spectator diagram) and the 'W-exchange' process. The first graph has a  $m_Q^5$ -mass dependence, the second one  $m_Q^3$ . Fig.11 depicts the measured life time pattern of heavy hadrons<sup>12</sup>. The size of the box indicate the present accuracy. The latest measurements in the baryon sector have increased the accuracy for the  $\Xi_c^+$  (E687)<sup>13</sup> and  $\Lambda_b$  (CDF<sup>14</sup> and LEP<sup>15</sup>).

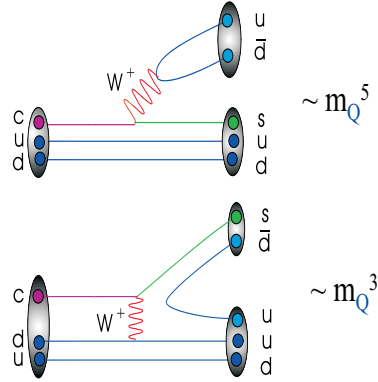


Figure 10. Two decay diagrams for the  $\Xi_c^+$ . The upper figure depicts the free quark decay, the lower one W-exchange. Other decay diagrams exist, not shown here.

In particular, the low lifetime of the  $\Lambda_b$  has become more significant. The central value for the world average is  $1.24 \pm 0.08 \text{ ps}$  (0.74 of the B-meson lifetime) and can not be accommodated by the present concepts and calculations.

Two conclusions may be drawn from this. The technique of Heavy Quark Expansion is not working for the b-sector and thus the quantitative agreement in the charm sector is pure coincidence<sup>16</sup>. Particular possibly hidden selection rules may alter the decay width of some dominant decay channels<sup>17</sup>.

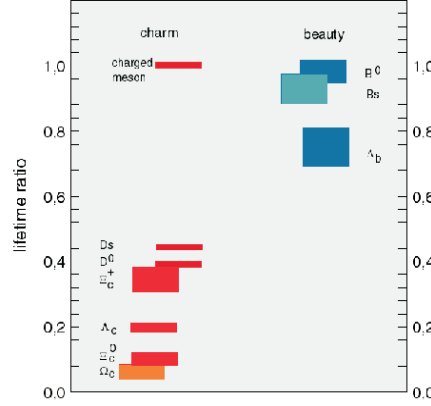


Figure 11. Measured lifetimes of heavy flavor hadrons. The vertical size of a bar gives the error on the measured values.

#### 4.2 Analysis of simple final states - Decay asymmetries

While the description of multi-body decays, which constitutes a large part of the observed total decay width of heavy baryons, is very difficult to describe theoretically, simple final states (like two-body decays or three-body semi-leptonic decays) may be calculated. This is possible if we assume the factorization of the decay process<sup>18</sup>:

- separate W-emission and W-decay vertex (heavy quark transition)
- Only assume spectator diagram (W-emission) (see fig.10 upper graph)
  - W-decay into lepton pair ( $l^\pm \nu$ )  $\rightarrow$  semi-leptonic decay
  - W-decay in  $\pi$  (or K-Cabibbo suppressed)  $\rightarrow$  two-body non-leptonic decays

then:

- for very heavy baryons  $\Gamma_{s.l.} = \Gamma_{s.l.}^{freequark}$  - branching ratio (b.r.) is indicator for importance of quark correlations to lifetime (see  $D^\pm$  with b.r. (semi-leptonic)  $\sim 15\%$ )
- predict 2-body decay asymmetries for  $\Lambda$ -type baryons

- $\Lambda_c \rightarrow \Lambda \pi$   $\alpha=-1$
- $\Xi_c \rightarrow \Xi \pi$   $\alpha \leq 0$  (W-exchange is important)
- HQET can make predictions (only 2 decay amplitudes may remain)

Typically, weak decay asymmetries are caused by the interference of S- and P-waves in the decay of the mother baryon. This leads to parity violation which is manifested in a polarization of the daughter particles or in an asymmetry in their decay angle with respect to the polarization of the mother baryon, both governed by the analyzing power  $\alpha$  of the decay. Thus, the analysis of the daughter polarization can be used to study the analyzing power in a specific decay channel (see fig. 12). HQET predicts a strong correlation between s.l. decay asymmetries and non-leptonic two-body decays of type  $\Lambda_c \rightarrow \Lambda$  for  $q^2=0$ , predicting  $\alpha_{\Lambda_c}=-1$  (as observed by CLEO<sup>19</sup>). Recently, non factorizing diagrams have also been included in the calculations leading to more realistic predictions of the decay properties<sup>20</sup>.

Recently CLEO has made the first measurement on a decay asymmetry of the  $\Xi_c^0$  observing the triple cascade  $\Xi_c \rightarrow \Xi^- \pi^+$ ,  $\Xi^- \rightarrow \Lambda \pi^-$ ,  $\Lambda \rightarrow p \pi^-$ <sup>21</sup>. Using the known decay asymmetries for the hyperons the decay asymmetry of the 2-body decay channel could be determined. The preliminary result is  $\alpha_{\Xi_c^0} = -0.56 \pm 0.39$ . This can be compared to the analog decay  $\Lambda_c \rightarrow \Lambda \pi^-$  with  $\alpha_{\Lambda_c^+} = -0.94^{+0.21}_{-0.06}$ .

Although statistically still poor this measurement prefers predictions with negative sign of the analyzing power.

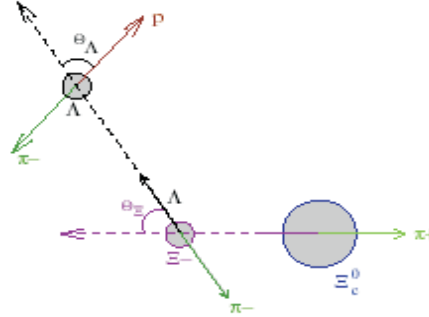


Figure 12. Determination of the decay asymmetry of a  $\Xi_c$ , using the decay chain with self-analyzing hyperons

## 5 Is Their Life After Death ?

After having spent many decades on the study of heavy (predominantly charmed) baryons we shall discuss the role of heavy baryons in future experiments. We may distinguish two fields, the search for new heavy baryonic systems and the use of heavy baryons as tools to study other physics subjects.

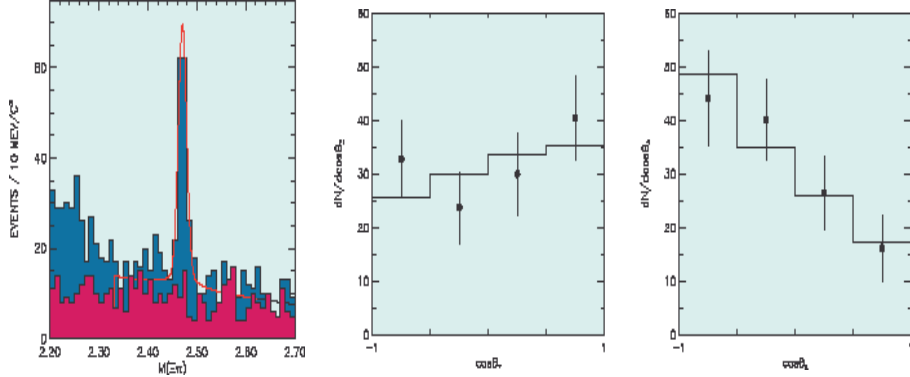


Figure 13. Underlying signal for the two-body asymmetry analysis of the  $\Xi_c$  (left) and angular asymmetries observed (right two plots). The angular distributions (data points) are compared with MC-calculations (histogram) based on the resulting asymmetry parameter.

### 5.1 Future Cultures

The investigation of new systems comprises ordinary baryons and exotica. The next system which might be investigated are double charmed baryons. The physics of these lies in the spectroscopy<sup>23</sup> and the lifetime pattern observed for different flavor states.

While the ground state of such a system looks like a deuterium atom with the two charm quarks taking the role of the nucleus, the first excited levels may have molecular structure with *vibrational* states of the two heavy quarks building the lowest levels of the excitation spectrum. The lifetime pattern of the different possible flavor states should enable us to unravel the different long distance contributions mentioned above as only one additional process adds to the spectator diagram, a different one for each baryon type.

However, we will face experimental difficulties. The cross sections at  $e^+e^-$  machines are very low and still low in fixed target production. High beam intensities are required (see e.g. COMPASS<sup>24</sup>, BTeV<sup>25</sup>) and very high energy may be necessary to boost the cross section for double charm production (see  $B_c$ -production at the Tevatron). In addition to the production the detection is non straight forward. Four decay vertices from the 4 charm quarks produced in the interaction have to be disentangled on very short distances.

### 5.2 Heavy Baryons as a tool - the case of polarization

We may use the production properties of heavy baryons as a tool to measure other physics parameters. The analyzing power in two-body and semi-leptonic decays can be used to measure their production polarization. Those can be used to measure:

- quark polarization in Z-decays  
The standard model gives predictions of large polarization of the b-quarks. This can be used to measure the polarized fragmentation function or, in turn test the b-quark polarization in some specific kinematic region<sup>22</sup>. First results have already be obtained for the  $\Lambda_b$  polarization showing a surprisingly low value of  $\rho_{\Lambda_b} = -23^{+24}_{-20}(\text{stat.})^{+8}_{-7}(\text{syst.})\%$ .
- polarization of gluons in polarized nucleons  
The production of polarized  $\Lambda_c$  has already been discussed within the COMPASS<sup>24</sup> experiment as an alternate tool to measure the spin polarization of gluons. Using deep inelastic muon scattering c-quarks are produced by the photon-gluon fusion process. Baryons are subsequently formed in their fragmentation. Owing to the production process the polarization of the c-quarks will follow the gluon polarization in the nucleon. If we were to follow SU(3) w.f. the c-quark determines the spin-direction of the  $\Lambda_c$ . We may thus use two-body decays with large analyzing power to determine the  $\Lambda_c$ -polarization in the standard asymmetry measurements using the polarized fragmentation functions derived e.g. from LEP. Knowing the gluon polarization in the nucleon we could reverse the argument and determine the c-quark polarization in a polarized  $\Lambda_c$ .

### 5.3 Other fields of interest

We may briefly enumerate a number of other interesting measurements still to be done in the sector of heavy baryons.

- precise knowledge of form factors in semi-leptonic decays
- b-baryon spectroscopy
- spectrum of excited c-baryons (are they still narrow ?)
- magnetic moments (needs very high energy beams(e.g. 8 TeV extracted beams), high intensity, observation of spin precession in e.g. crystal)

Last not least we shall remember, that the search of doubly strange dibaryons has not yet revealed any sign of their existence (see experiments at BNL <sup>26</sup>, KEK <sup>27</sup> and CERN <sup>28</sup>) and that hybrid baryons are still discussed as possible candidates for exotic objects.

## 6 Conclusion

We have given a survey of the different physics surrounding the study of heavy baryons.

It has been shown that hadro-production reveals interesting features not found in simple models of quark fragmentation and that total charm cross sections still show large systematic uncertainty both from theory and experiment.

The study of static properties of heavier baryons is being pursued and first measurements of the charge radius of a strange baryon has been reported. The spectroscopy of charmed baryons has seen further discoveries in orbitally excited states supporting the scheme of decoupling of heavy and lighter quark degrees of freedom.

The lifetime puzzle in the b-quark sector persists. Still the precision in baryon lifetimes is not yet high enough to definitely challenge existing model calculations. Big progress is also at the horizon in the field of decay asymmetries, a subject not understood in the sector of lighter systems. Last not least it should be mentioned, that most of the recent data stem from photo-production in either photon-beams or  $e^+e^-$ -colliders which offer clean environment even for the study of low cross section processes.

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